Global Hot Gas in and around the Galaxy

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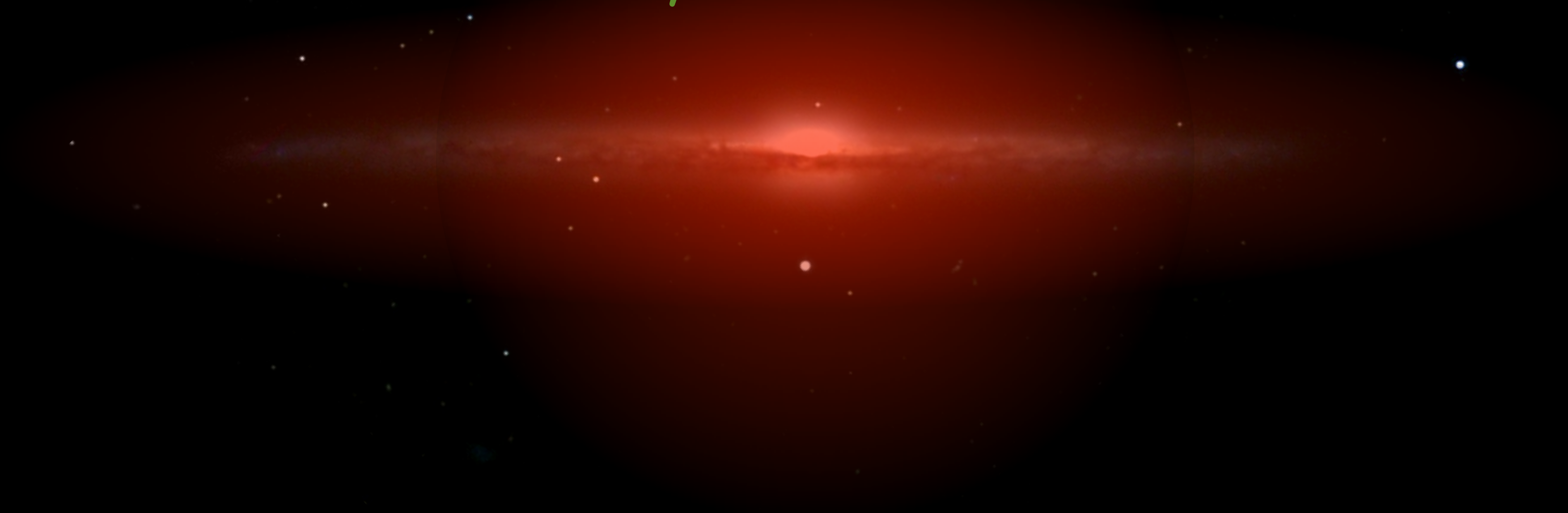
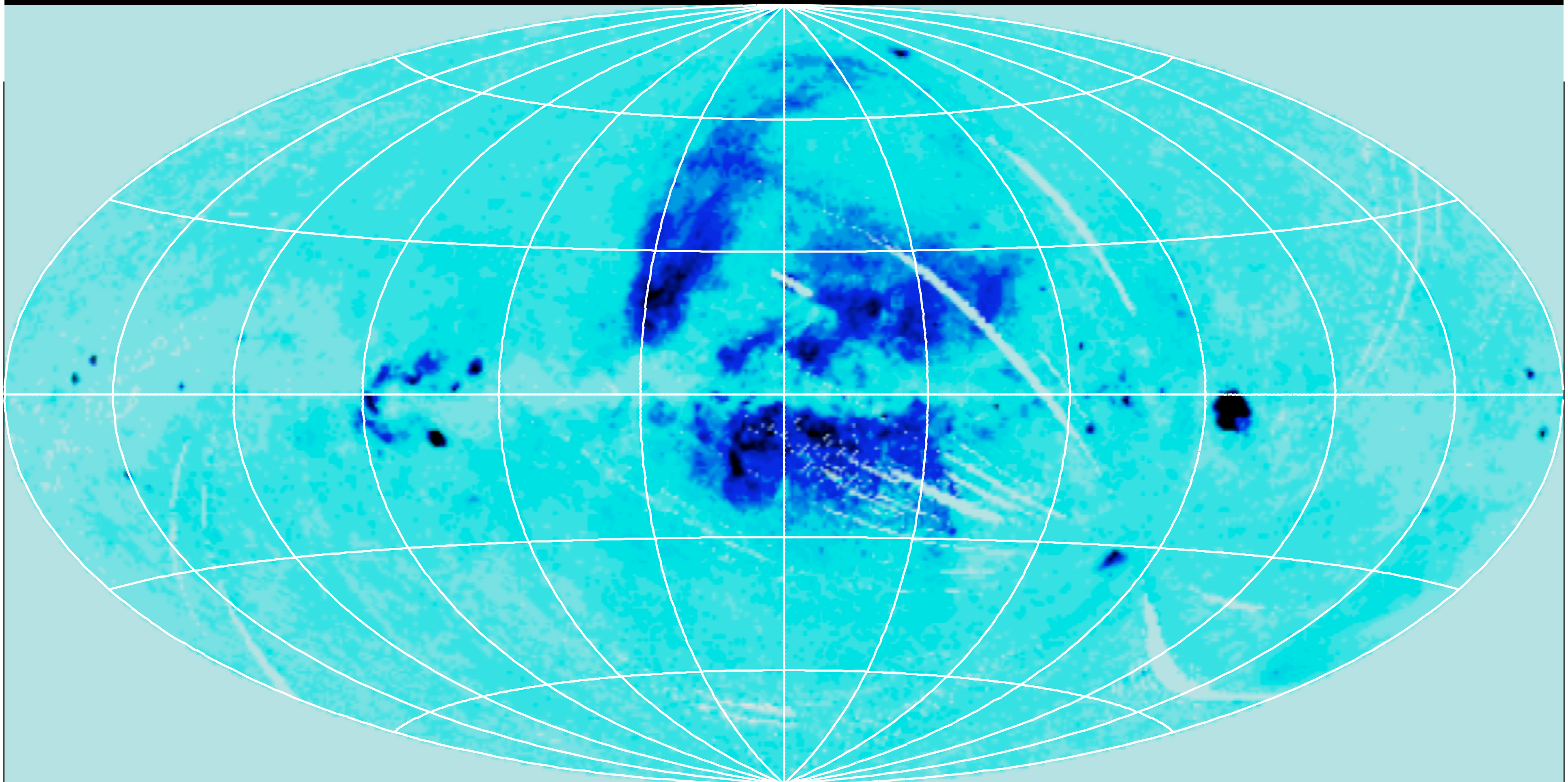
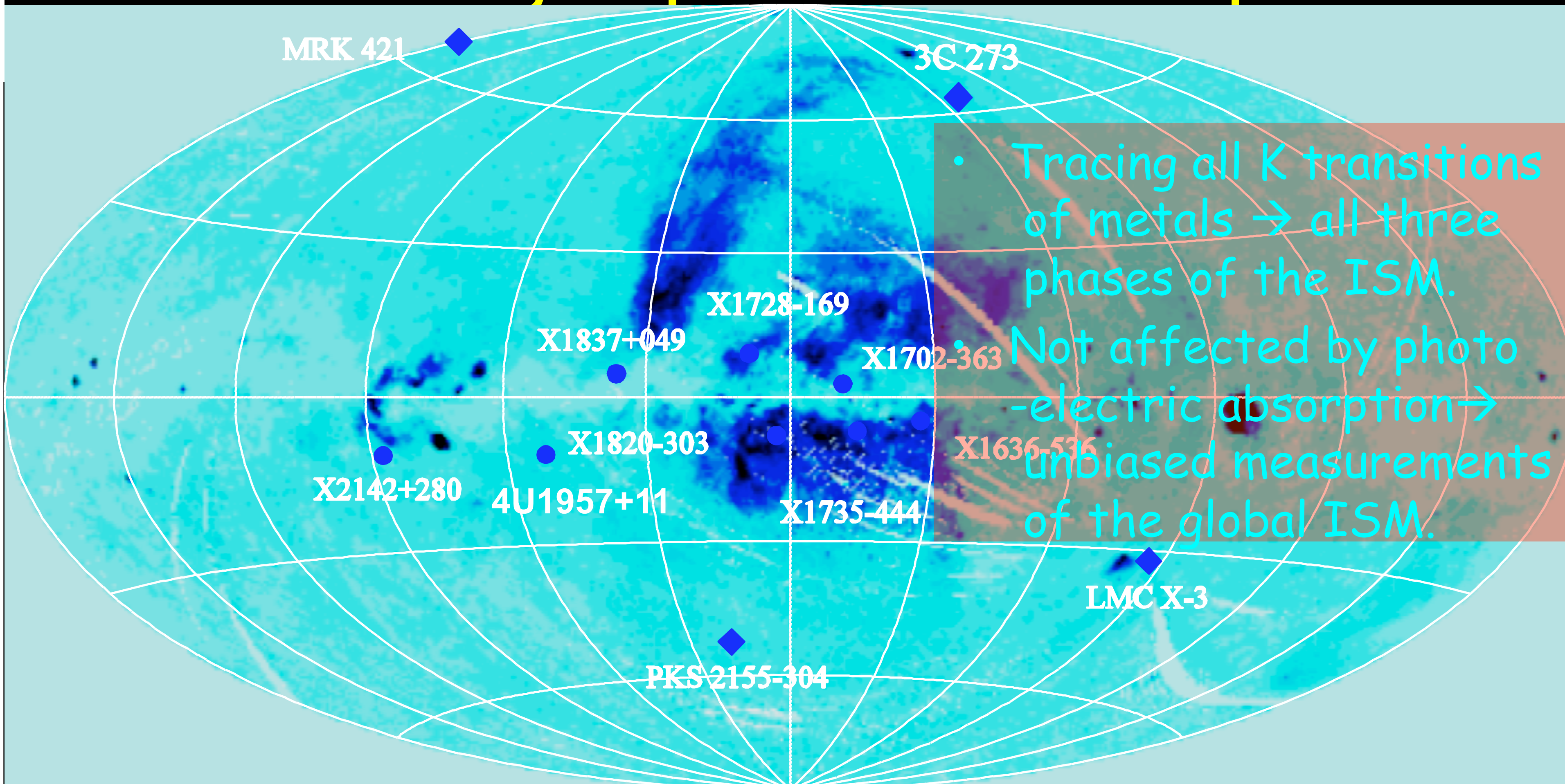


Pre-Chandra View of the hot gas



ROSAT ¾-keV Diffuse Background Map:
~50% of the background is thermal and local ($z < 0.01$)
The rest is mostly from faint AGNs (McCammon et al. 2002)

X-ray absorption line spectroscopy: adding depth into the map



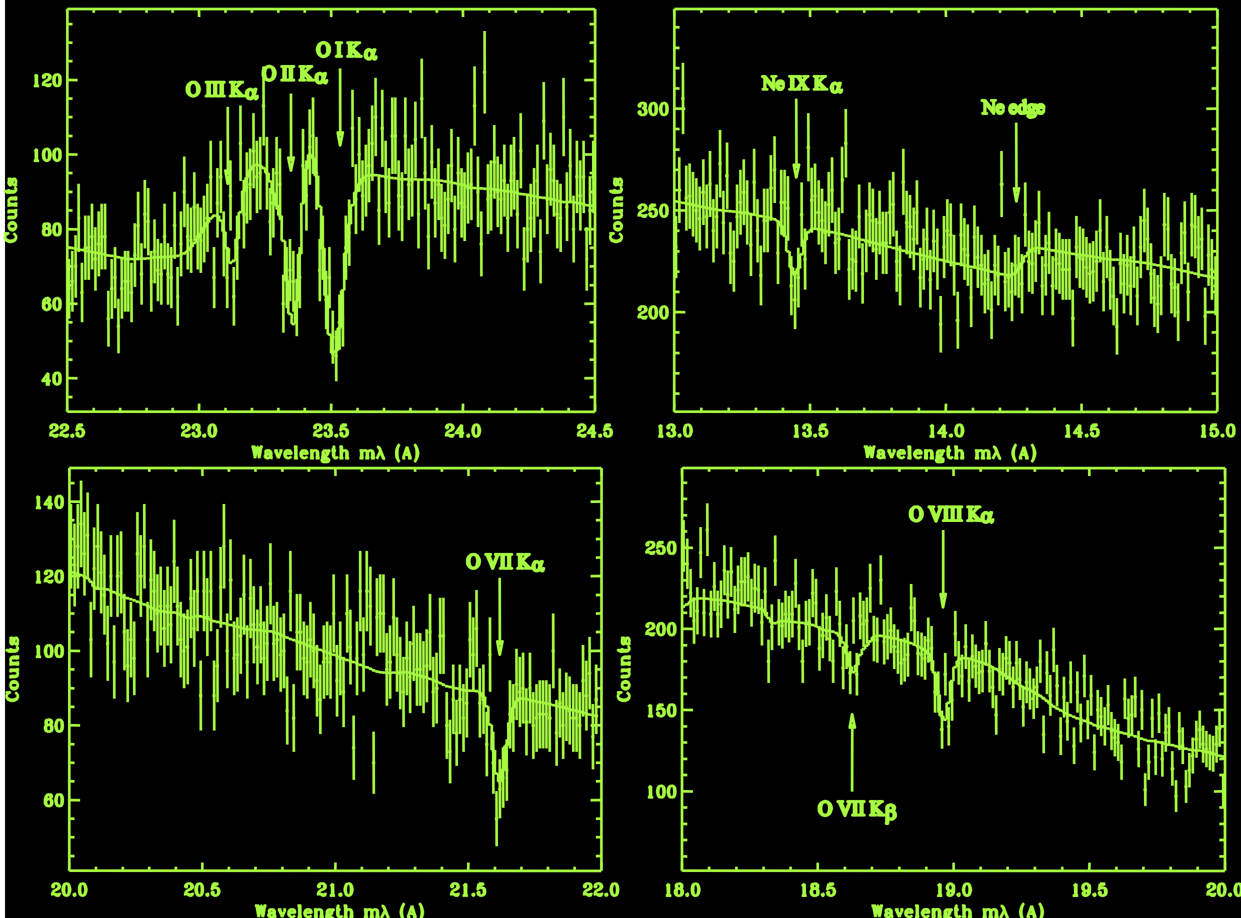
- Tracing all K transitions of metals → all three phases of the ISM.
- Not affected by photo-electric absorption→ unbiased measurements of the global ISM.

◆ AGN
● X-ray binary

Wang et al. 05, Yao & Wang 05/06, Yao et al. 06/07

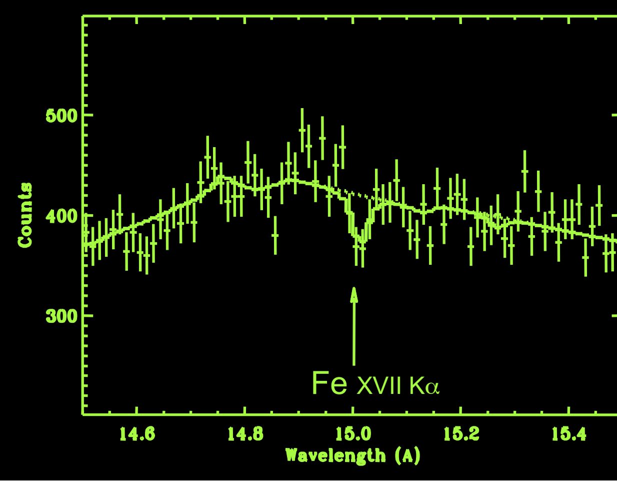
ROSAT all-sky survey in the $\frac{3}{4}$-keV band

LMXB X1820-303



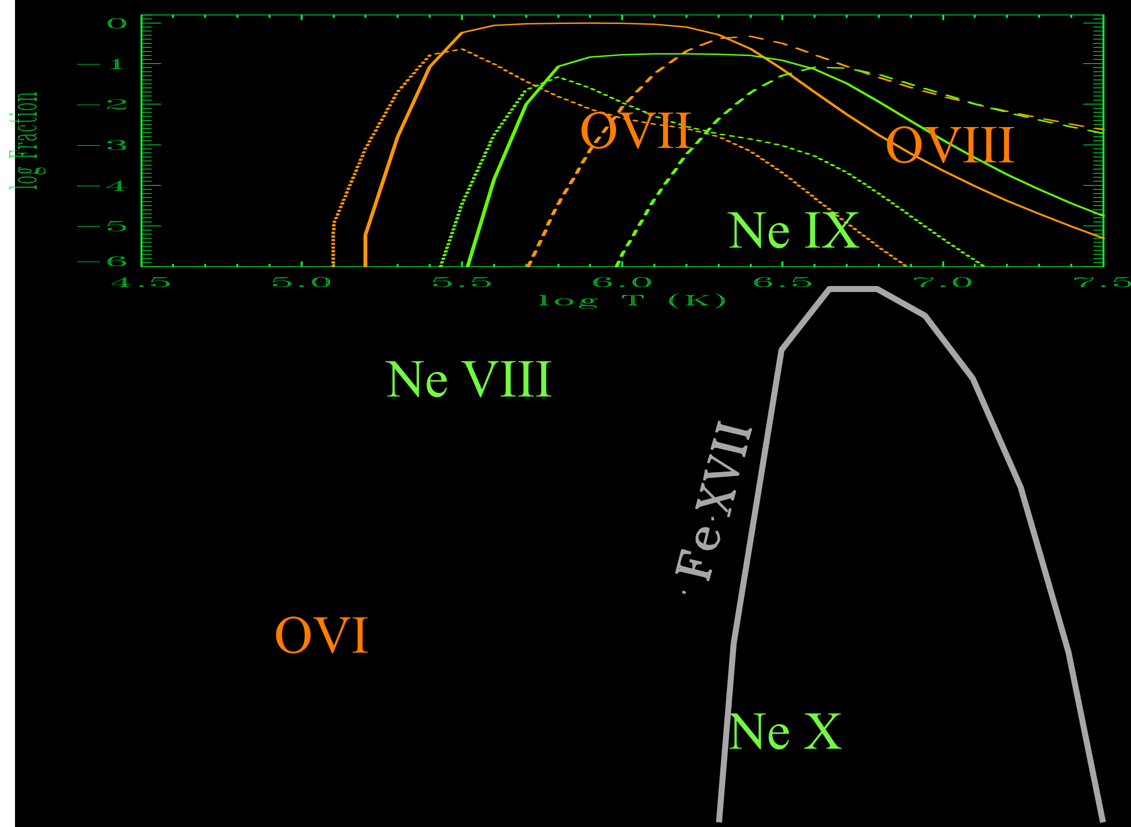
LETG+HETG spectrum

- In GC NGC 6624
  - *l*, *b* = 2°.8, -8°
  - Distance = 7.6 kpc → tracing the global ISM
  - 1 kpc away from the Galactic plane → N_{HI}
- Two radio pulsars in the GC: DM → N_e
- Chandra observations:
  - 15 ks LETG (Futamoto et al. 2004)
  - 21 ks HETG



Yao & Wang 2006, Yao et al. 2006

Absorption line diagnostics



$$I(\nu)=I_c(\nu)\ \exp[-\tau(\nu)]$$

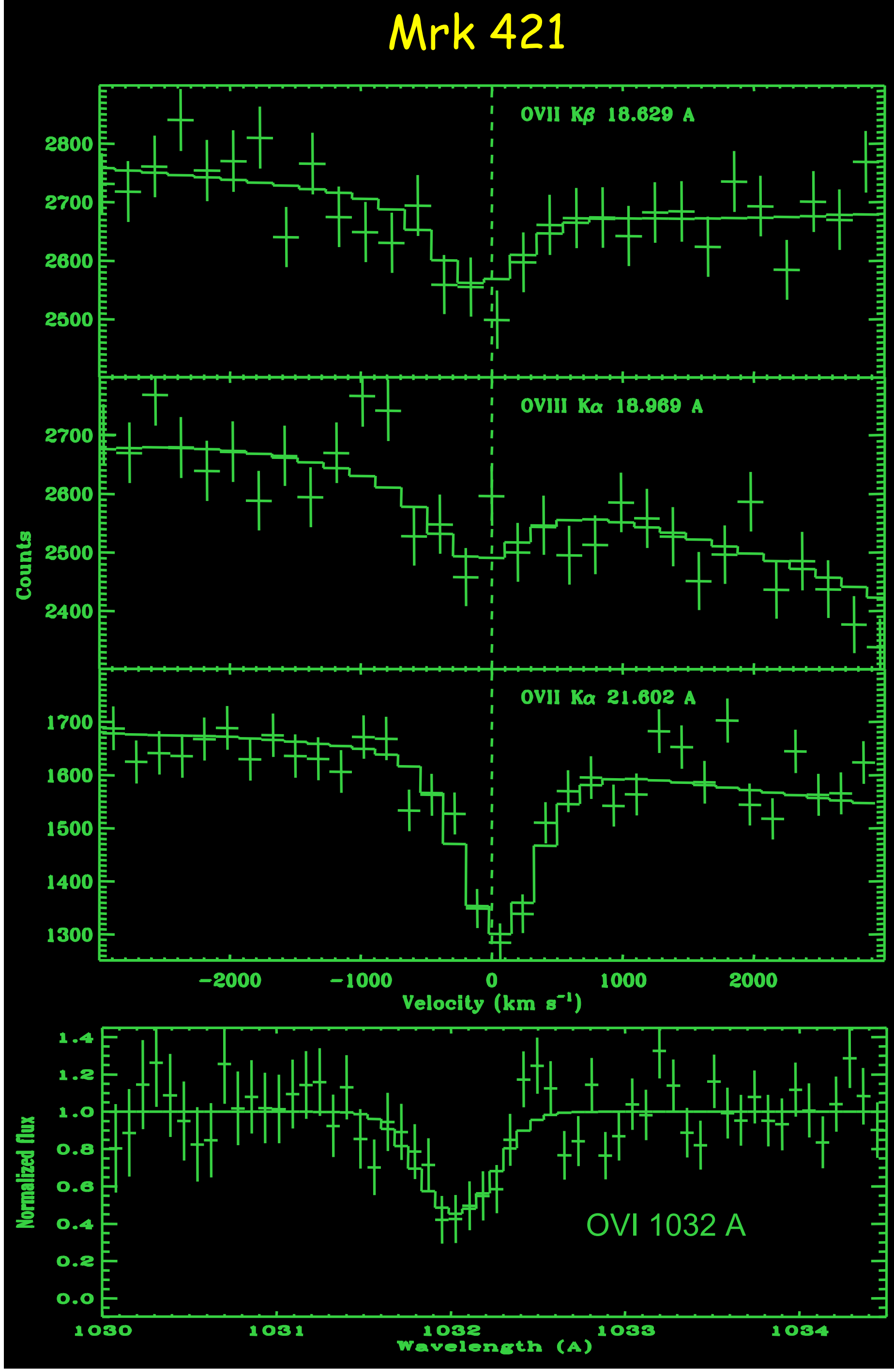
$$\tau(\nu)\propto N_H f_a f_i(T) f_{lu} \phi(\nu,\nu_0,b)$$

$$b=(2kT/m_i+\xi^2)^{1/2}$$

Accounting for line saturation and multiple line detections

Assuming CIE and solar abundances

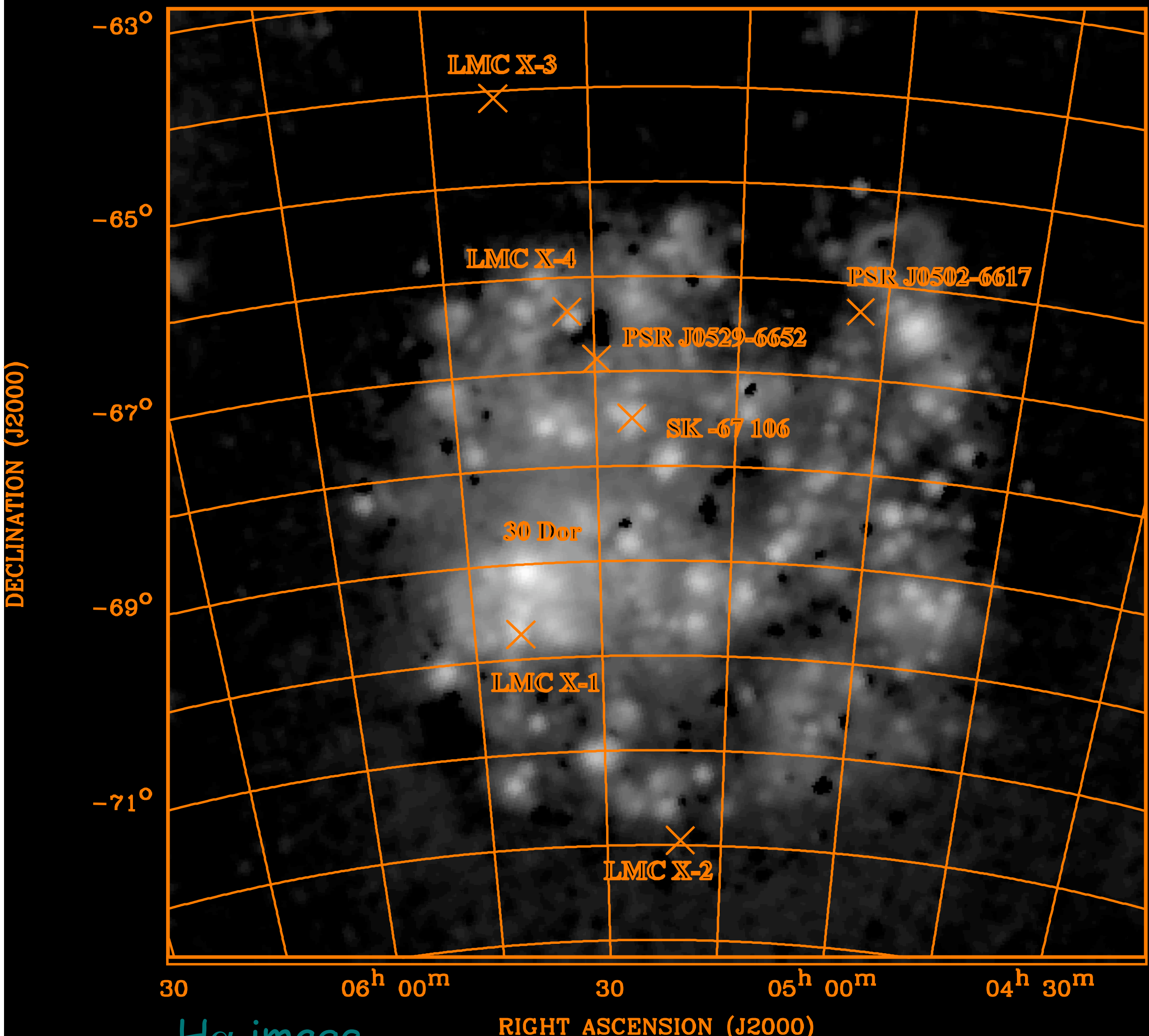
Yao & Wang 2005



Spectroscopic diagnostics

- One line (e.g., OVII Kα) → velocity centroid and EW → constraints on the column density, assuming b and T
- Two lines of different ionization states (OVII and OVIII Kα) → T
- Two lines of the same state (Kα and Kβ) → b
- Lines from different species → abundance f_a
- Joint-fit of absorption and emission data --> pathlength and density
- Two sightlines --> differential hot gas properties

LMC X-3 as a distance marker

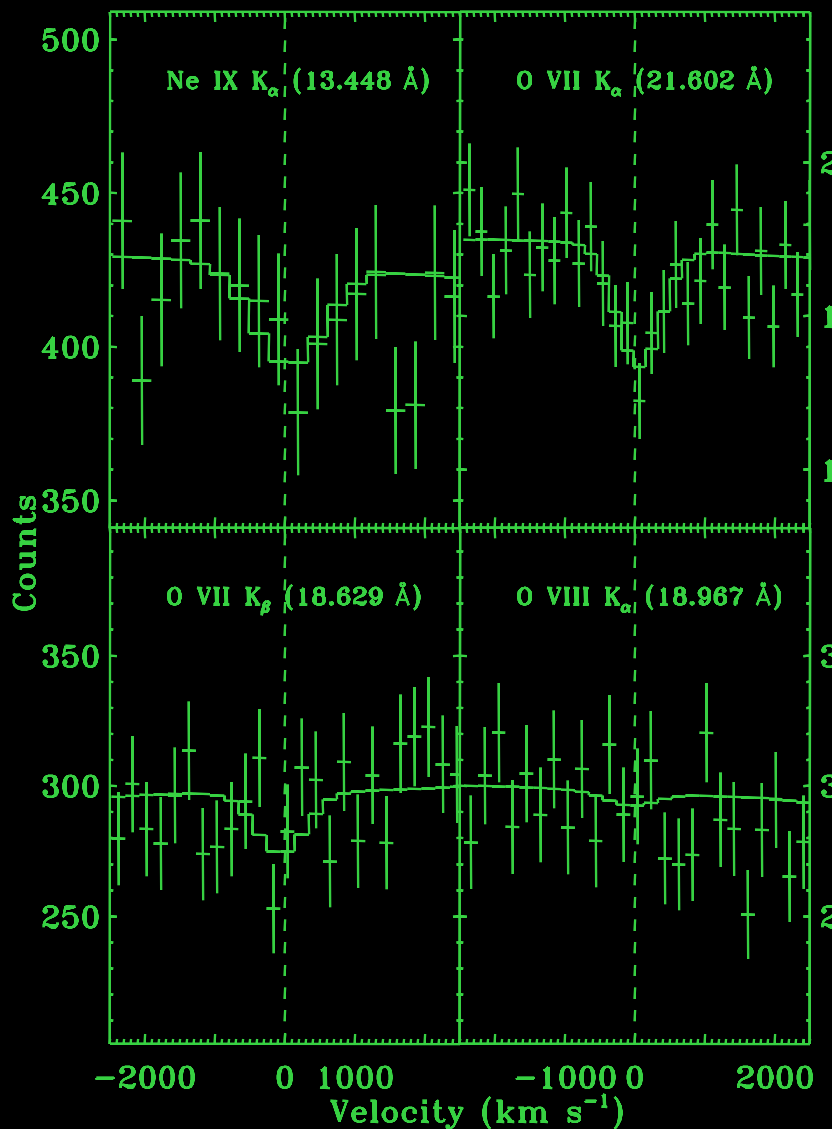


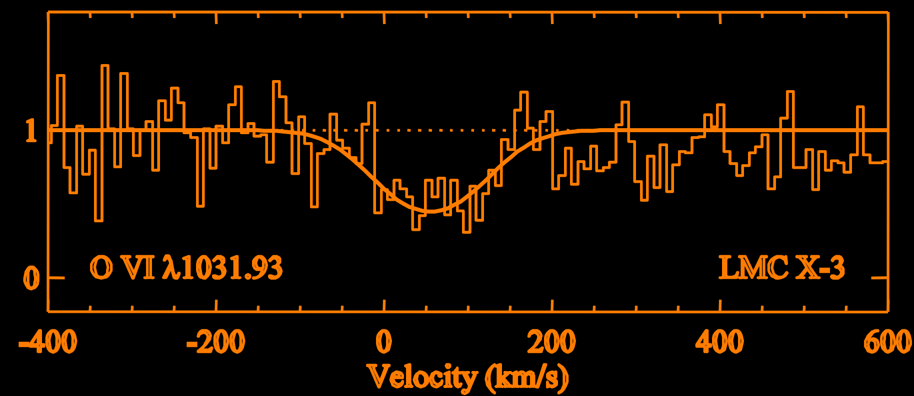
Hα image

- BH X-ray binary undergoing Roche lobe accretion
- 50 kpc away
- V_s = +310 km/s
- Away from the LMC main body

Wang et al. 2005

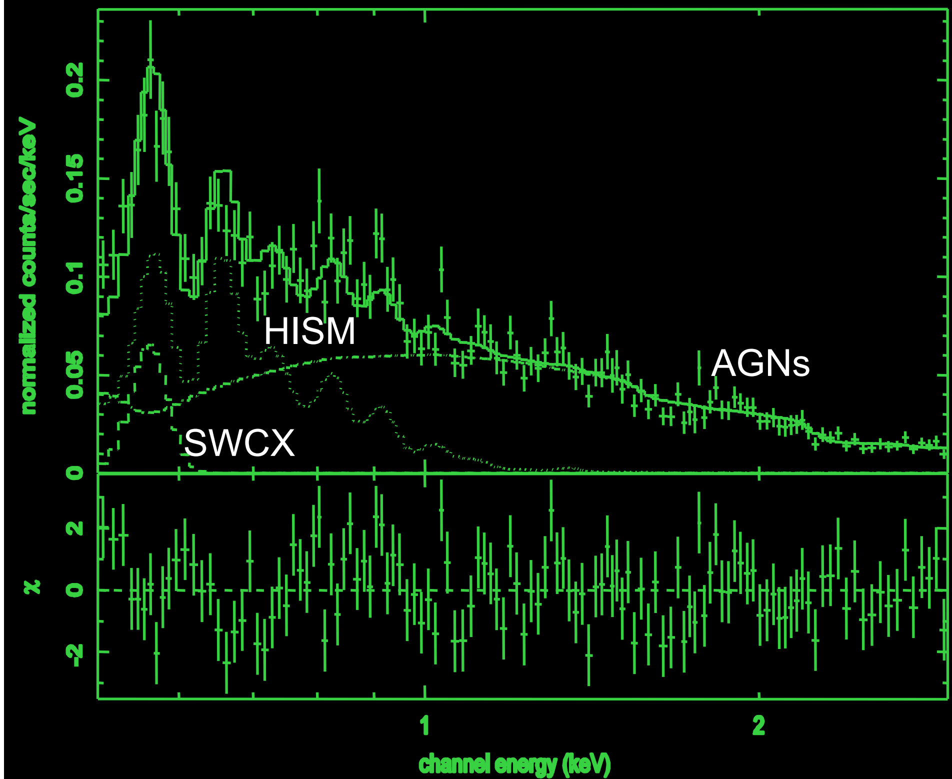
LMC X-3: absorption lines





- The line centroids of the OVI and OVII lines are consistent with the Galactic origin.
- $N_o \sim 1.9 \times 10^{16}$ atoms/cm^2, similar to those seen in AGN spectra!
- $v_b \sim 79$ km/s
- $T \sim 1.3 \times 10^6$ K

Joint-fit to the Suzaku XIS diffuse emission spectrum



100 ks Suzaku observations of LMC X-3 off-fields

(Yao, Wang, et al. 2008)

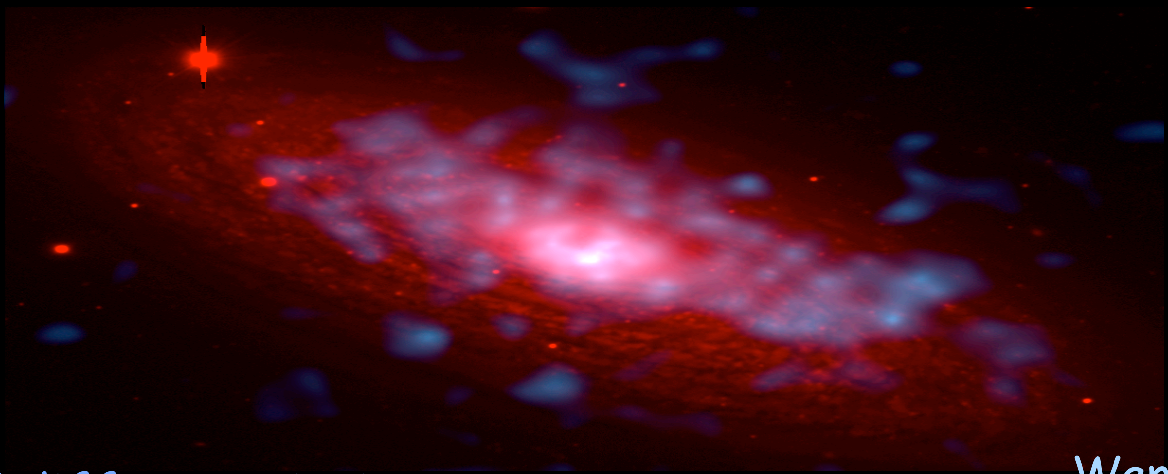
- Single temperature fit → T= 2.4×10^6 K, significantly higher than that inferred from the X-ray absorption lines.
- Joint-fit to the absorption and emission data gives
  - n_e= (3.6×10^{-3} K) $e^{-|z|/2.8\ \mathrm{kpc}}$;
  - T= (2.4×10^6 K) $e^{-|z|/1.4\ \mathrm{kpc}}$

  → P/k ~ 1.1×10^4 cm^{-3} K, assuming filling factor =1.
  - So in comparison, the LHB may be slightly under-pressured!
  - This thick hot disk can explain all the OVI absorption, but only ~10% of high-*b* OVI emission.

Galactic global hot gas properties

- Structure:
  - A thick Galactic disk with a scale height ~2 kpc, ~ the values of OVI absorbers and free electrons
  - Enhanced hot gas around the Galactic bulge
- Thermal property:
  - mean T ~ $10^{6.3}$ K toward the inner region
  - ~ $10^{6.1}$ K at solar neighborhood
- Velocity dispersion from ~200 km/s to 80 km/s
- Abundance ratios consistent with solar:
  - Ne/O =1.4(0.9-2.1) solar (90% confidence)
  - Fe/Ne = 0.9(0.4-2.0) solar (including part of the bulge); but Fe is strongly depleted in the disk, indicating enhanced Fe abundance in the bulge.

NGC 2841 (Sb)

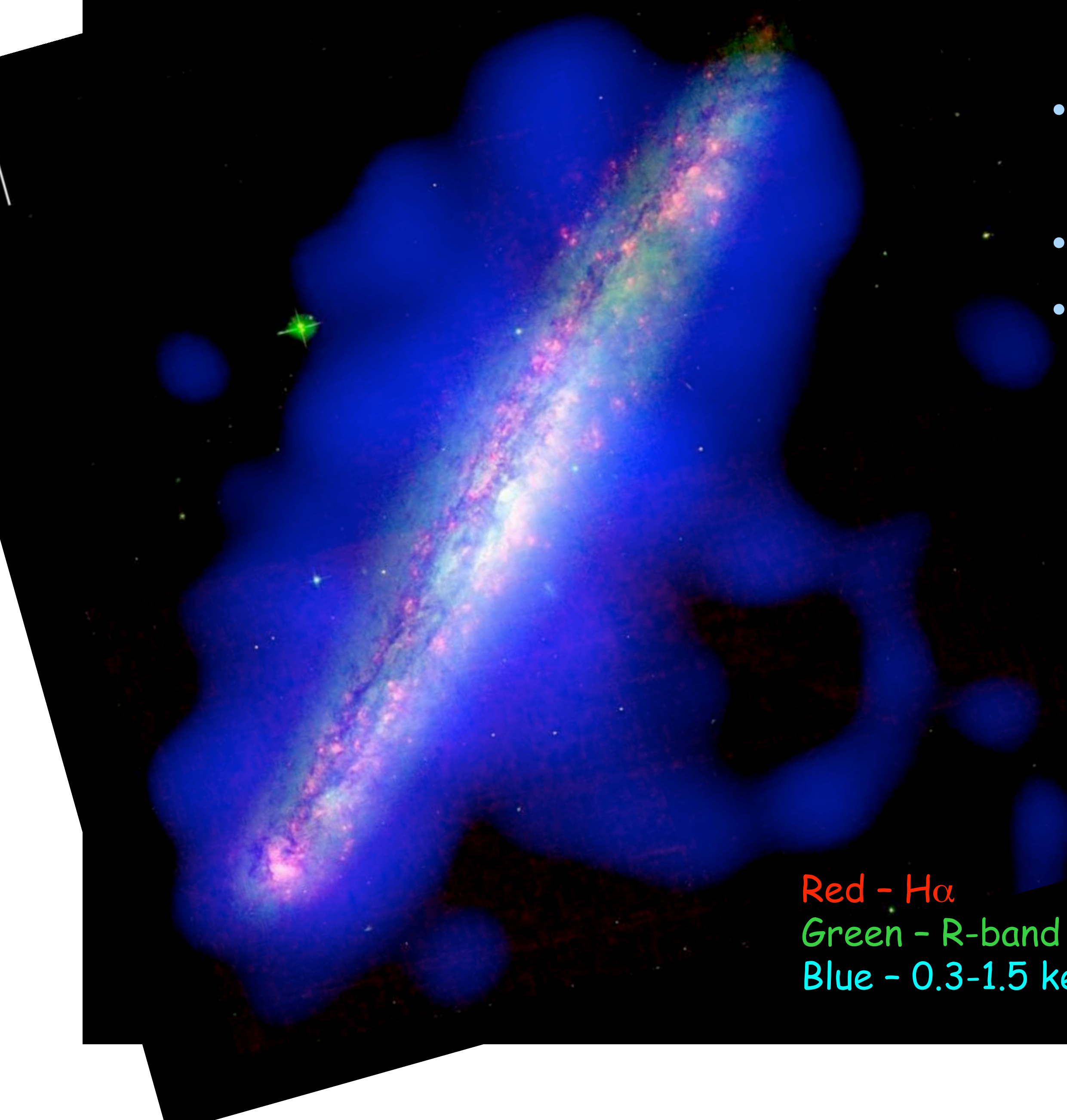


Red: optical

Blue: 0.3-1.5 keV diffuse emission

Wang et al. 2006

NGC 5775

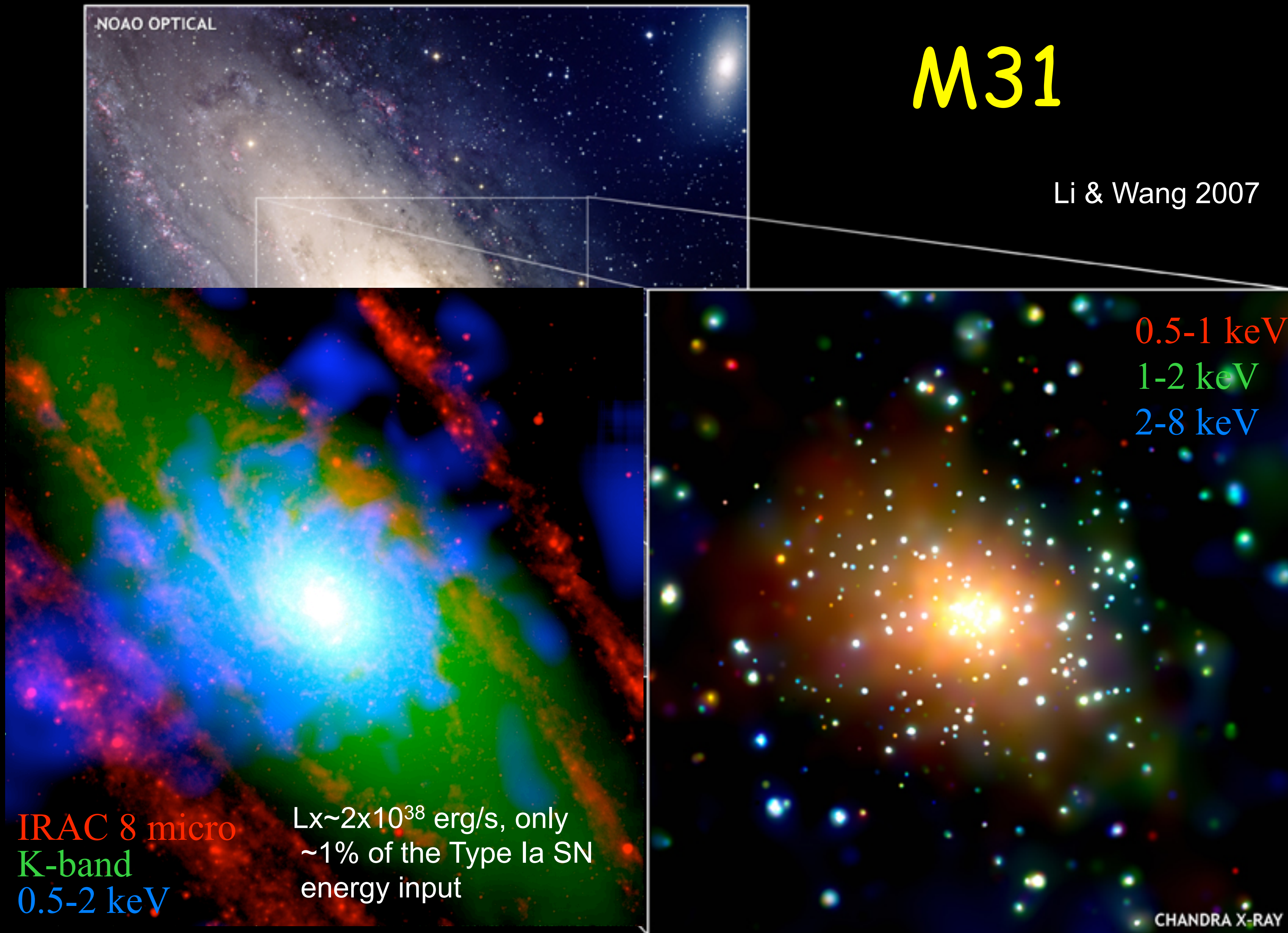


- Scale height ~ 2 kpc + more distant blubs.
- $T_1 \sim 10^{6.3}$ K, $T_2 > 10^{7.1}$ K
- L_x(diffuse) ~ 4×10^{39} erg/s, ~1% of the expected SN energy input!

Li et al. (2008)

M31

Li & Wang 2007

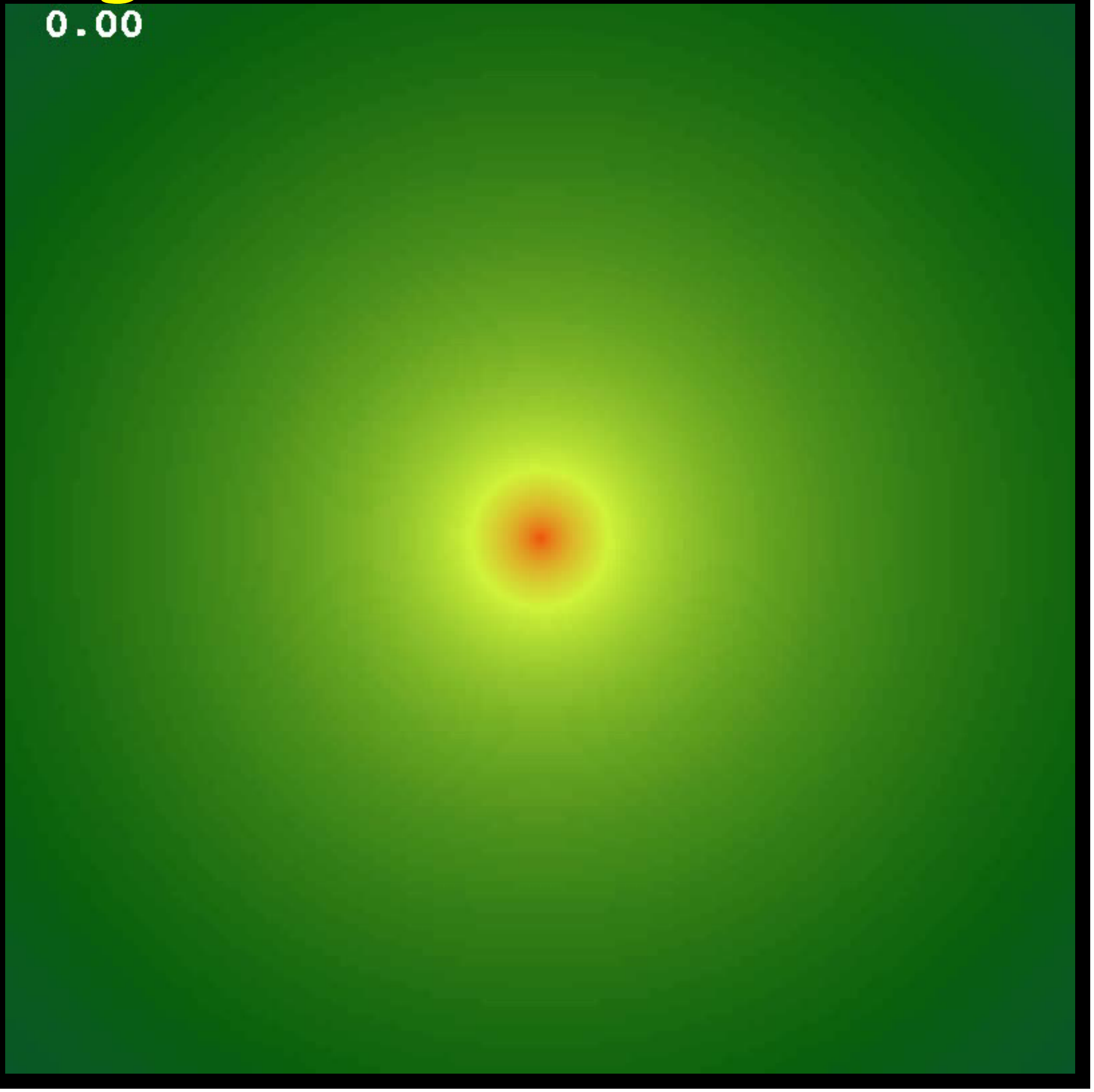


3-D simulations of a galactic bulge wind

- Adaptive mesh refinement, down to 6 pc
- Stellar mass injection and sporadic SNe, following the stellar light.
- Almost all energy is escaped into the halo.

10x10x10 kpc^3 box

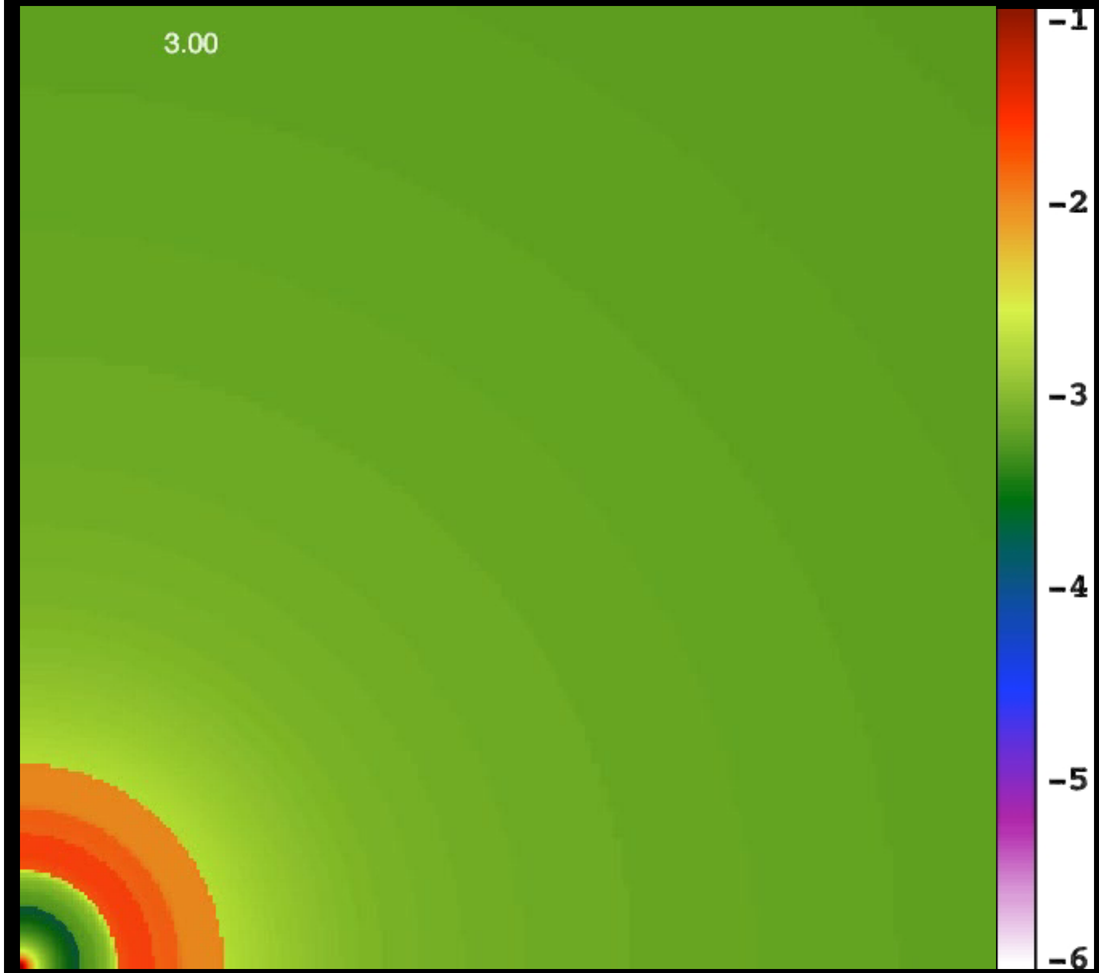
density distribution



Summary

- Diffuse hot gas is strongly concentrated toward galactic disks/bulges (< 20 kpc) due to the stellar feedback.
- But the bulk of the feedback is not detected in X-ray and is probably propagated into large-scale halos, which can help to solve the "overcooling" problem in existing galaxy formation theories.
- Such a hot gaseous halo is also required to explain HVCs:
  - Confinement
  - Head-tail morphology
  - OVI absorption
- But the hot gas density of the Galactic halo must be small to be consistent with X-ray data, $N_H < 1 \times 10^{19}$ cm^{-2}

Interplay between the gas accretion and stellar feedback around a Milky Way-like galaxy



Density evolution; box size = 0.5 Mpc

Tang et al., Tang & Wang 2008

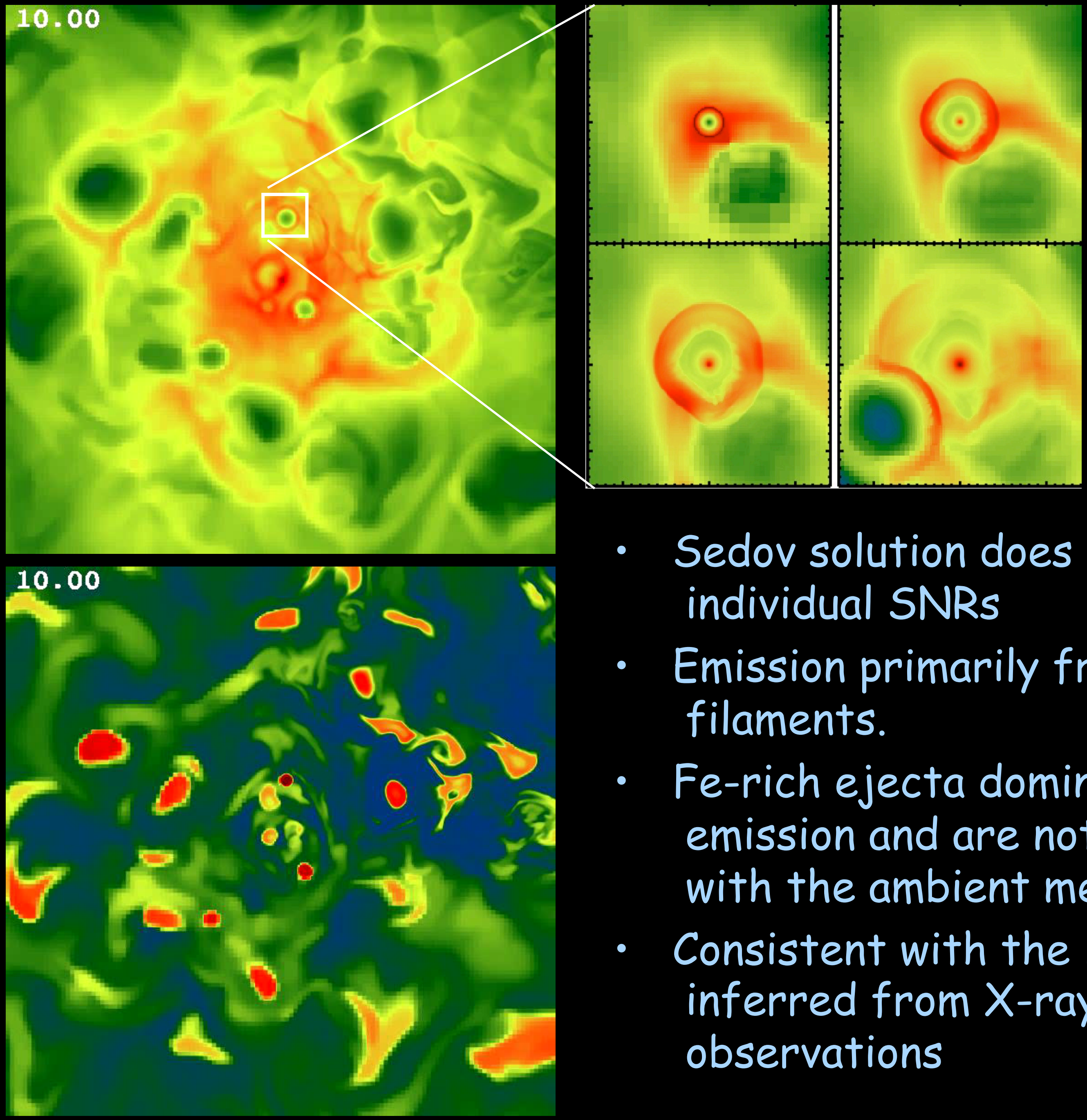
- Both dark and baryon matters trace each other initially and evolve with to a final mass of 10^{12} Msun (see also Birnboim & Dekel 03)
- A blastwave is initiated by a starburst (+AGN) and maintained by the Type Ia SN feedback + stellar winds from evolved stars.
- IGM is heated beyond the virial radius, and accretion can be stopped.

Conclusions

The feedback from a galaxy likely plays a key role in galaxy evolution:

- Initial burst led to the heating and expansion of gas beyond the virial radius
- Ongoing feedback keeps the gas from forming a cooling flow and starves SMBHs
- Mass-loaded outflows may account for diffuse X-ray emission from galactic bulges.
- Condensation of the burst material may account for some HVCs.

Our Galaxy resides in a hot bubble!



- Sedov solution does apply for individual SNRs
- Emission primarily from shells and filaments.
- Fe-rich ejecta dominate the high-T emission and are not well-mixed with the ambient medium
- Consistent with the low metallicity inferred from X-ray spectral observations